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A New Facility for Advanced Rocket Propulsion Research

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ABSTRACT

A new test facility has been constructed at the NASA Lewis Research Center Rocket Laboratory for the purpose of conducting rocket propulsion research at up to 8.9 kN (2000 lb_f) thrust, using liquid oxygen and gaseous hydrogen propellants. A laser room adjacent to the test cell provides access to the rocket engine for advanced laser diagnostic systems. The size and location of the test cell provide the ability to conduct large amounts of testing in short time periods, with rapid turnover between programs. These capabilities make the new test facility an important asset for basic and applied rocket propulsion research.

INTRODUCTION

Computer codes modeling rocket combustion phenomena, and diagnostic tools for validating these codes, have become more advanced, and facilities are required which provide easy access for advanced, laser-based diagnostic equipment. In the current fiscal era, rapid turnaround times and high productivity are also required. For these reasons, the Advanced Rocket Propulsion Facility (ARPF) has been created at the NASA Lewis Research Center.

By providing this productive environment for basic rocket propulsion research, the ARPF can greatly improve our understanding of rocket propulsion, and can play a large part in the creation of new methodologies for designing the next generation of rocket engines. These capabilities make the ARPF an important asset to NASA and the propulsion industry.

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FACILITY OVERVIEW

An aerial view of part of the Rocket Laboratory at NASA Lewis, which consists of a number of small test facilities designed for rocket propulsion and related research, is shown in Figure 1. The ARPF complex, at the top left of the figure, is surrounded by steel and earthen bunkers and mounds.

Figure 1: Aerial View of the Rocket Laboratory

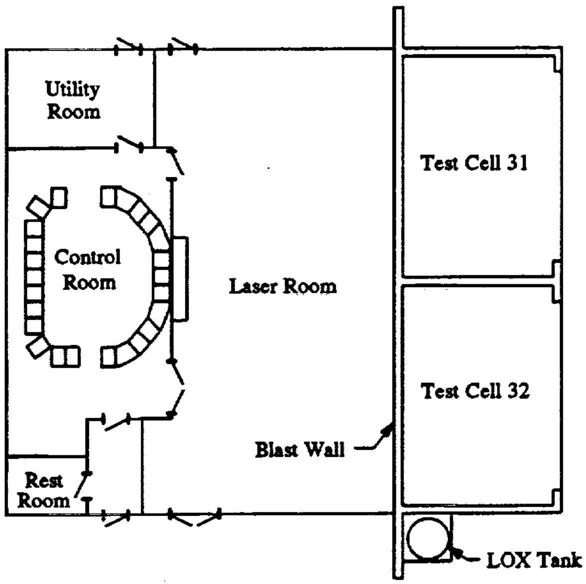

Figure 2: Schematic of the ARPF

Figure 2 provides a schematic view of the complex. The major components of the ARPF are the two test facilities, called Cell 31 and Cell 32, the laser diagnostics room, and the operations control room. This report details the capabilities of cell 32, while test cell 31 will be developed at a later date. The test cells are identical 5.8 x 7.3 m (19 x 24 ft.) rooms, surrounded by 0.3 m (1 ft.) thick reinforced concrete walls and ceilings which protect the laser and control rooms from any possible blast which might occur in the test cell.

The main fuels for the facility are gaseous hydrogen and liquid oxygen (LOX), and both of these systems are shared by the two test cells. Gaseous methane can be used in place of hydrogen, and gaseous oxygen can be used instead of LOX. Since cells 31 and 32 share a common control room and the same propellant sources, they cannot be run simultaneously, although rapid switching between the two will be possible when cell 31 begins operation.

The 8.5 x 14.9 m (28 x 49 ft.) laser room provides a large area for laser diagnostic equipment, enabling the systems to be set up and checked out in place before use in rocket testing. The room is equipped with electrical power and water cooling systems suitable for many different types of lasers, as well as safety interlock circuits which ensure the safe operation of the lasers. Optical pass-throughs are built into the blast wall at several locations to allow access for laser beams or fiber optic cables. This allows the lasers and main components of the optical systems to be protected while still permitting access to the rocket engine for probes or transmitted laser beams. Multiple laser systems can be operated simultaneously if needed to provide greater diagnostic capability.

The control room for the ARPF houses all of the electrical and electronic equipment required to operate both the test facilities, including the control consoles, the programmable controller for sequencing valves, the data system interface equipment and monitors, and video equipment needed to monitor the test complex and engine hardware. Personnel are limited to the control room and laser room during engine firings.

MECHANICAL SYSTEMS

Table I provides a summary of the most important capabilities of test cell 32, which are described below.

Thrust Stand

Test cell 32 has a horizontally firing test stand with a capacity of up to 8.9 kN (2000 lb_f). The rocket exhaust is directed out through a large overhead door. The thrust stand, shown in Figure 3, is supported by two flexure frames, each of which has four flexure-plate linkages in the vertical plane perpendicular to the thrust

Table I. ARPF Test Cell 32 Capabilities

Max. Thrust	8.9 kN (2000 lb_f)
Max. Chamber Pressure	6.9 MPa (1000 psig)
Max. LOX Flow Rate	3.18 kg/s (7.0 lb_m/s)
Max. H_2 Flow Rate	1.36 kg/s (3.0 lb_m/s)
Max. H_2 Cool. Flow Rate	0.13 kg/s (0.275 lb_m/s)

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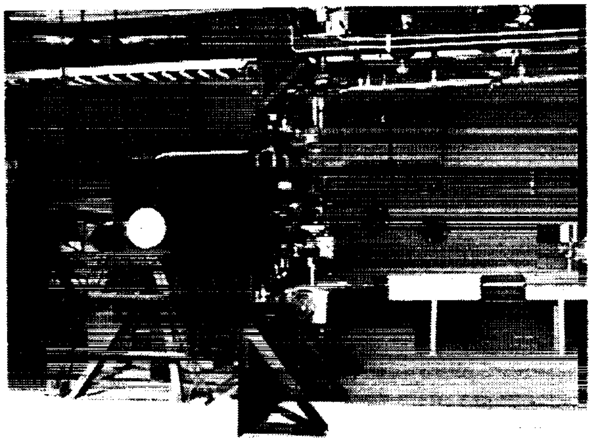

Figure 3: Cell 32 Thrust Stand

direction. A calibration load cell is used for each test set-up to measure a known load applied to the rocket engine using a hydraulic cylinder. This calibration measurement is necessary to determine the static spring forces due to the feed line connections to enable accurate thrust measurement during testing.

The test stand is surrounded on two sides by a steel bulkhead, 0.635 cm (0.25 in) thick. This provides a mounting surface for propellant and purge system valves, flowmeters, and instrumentation. It also provides some protection for facility components in the event of an engine explosion.

Main Propellant Systems

A simplified schematic of the primary hydrogen and oxygen propellant systems is shown in Figure 4. Gaseous hydrogen is supplied to either cell from a 1.98 million standard liter (70,000 standard cubic foot) tube trailer flowing through a 4.83 cm o.d. (1 1/2 in. SCH 40) pipeline, at mass flow rates of up to 1.36 kg/s (3.0 lb_m/s). Supply pressure is regulated at up to 13.8 MPa (2000 psig), and main engine flow is controlled with a hydraulically actuated valve. The same feed system can also be used to supply gaseous methane in place of hydrogen.

Gaseous oxygen is supplied from a similar system, utilizing a trailer with a 1.4 million standard liter (50,000 scf) capacity. A 4.83 cm o.d. (1 1/2 in. SCH 40) supply line carries oxygen from the trailer station to the building. Gaseous oxygen is used for ignition and for liquid oxygen pressurization, and it can also be used as a main propellant if desired.

The liquid oxygen (LOX) system consists of a 170 liter (45 gallon) insulated tank, with a 3.34 cm o.d. (1 in. SCH 40) liquid discharge line. The LOX line runs through a liquid nitrogen bath used to prechill the line and to maintain cryogenic temperatures during

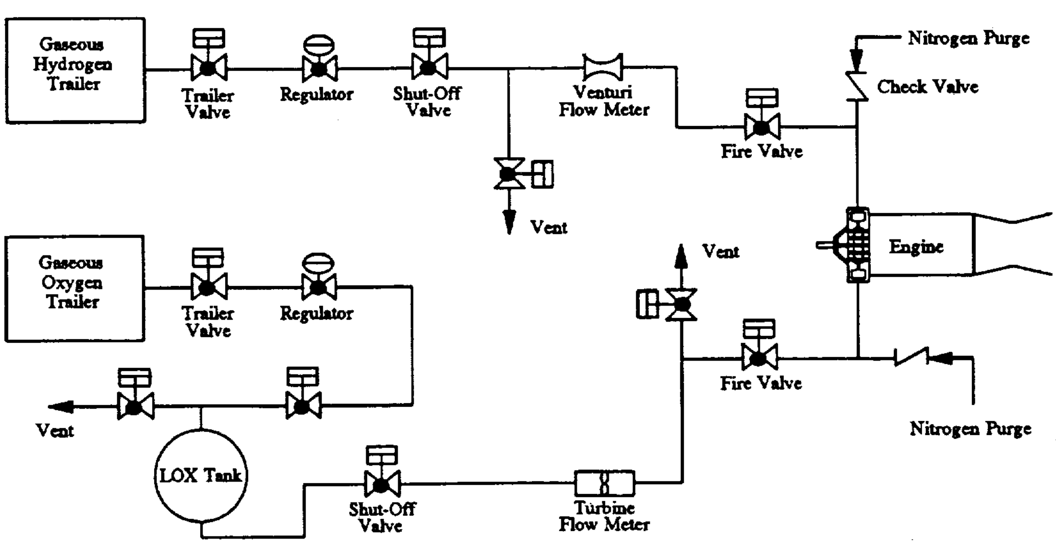

Figure 4: Schematic of the Main Propellant Systems

testing. Flow to the engine is measured using turbine flow meters. Control of the main oxygen flow is obtained with the use of a hydraulically actuated valve.

The liquid oxygen tank pressure is set at up to 10.3 MPa (1500 psig) using gaseous oxygen regulated with a dome-loaded regulator. Flows of up to 3.18 kg/s (7.0 lb_m/s) are obtainable. The flow rates and pressures supplied by the GH_2 and LOX systems provide a maximum thrust and chamber pressure of approximately 8.9 kN (2000 lb_f) and 6.9 MPa (1000 psig), respectively.

Both the GH_2 and LOX feed systems contain additional purge lines, relief valves, and instrumentation, not shown in Figure 4, which enable the facility to be operated in a safe manner. The LOX system also features burst disks and parallel vent valves for overpressure protection. All piping systems are fabricated from 300 series stainless steel pipe or tubing. Tubing systems use primarily 37 degree flare type fittings or ferrule type swaged fittings. Piping systems are welded construction with "Grayloc" couplings used throughout.

Ignition System

The ignition system is shown schematically in Figure 5. Gaseous hydrogen and oxygen are supplied from the main feed systems, and regulated to the required operating pressures with dome loaded regulators. A standard spark-ignited torch configuration is used for most test engines, with flow being controlled by the use of sonic orifices.

Standard ignition flows are 0.0028 kg/s (0.00625 lb_m/s) of H_2 at 4.3 MPa (625 psig) and 0.011 kg/s (0.025 lb_m/s) of O_2 at 3.6 MPa (525 psig). The ignition system can supply up to 0.025 kg/s (0.055 lb_m/s) of H_2 at 10.3 MPa (1500 psig), and 0.372 kg/s (0.82 lb_m/s) of O_2 at 10.3 MPa (1500 psig), making it possible to use the ignition system as a primary flow source for smaller gas/gas rocket engines if desired.

Purge Systems

The main facility and engine purges utilize nitrogen supplied from a 453,000 standard liter (16,000 scf) accumulator maintained at 15.5 MPa (2250 psig). Nitrogen is supplied to several regulator panels which allow individual purge pressures and propellant regulator dome loading pressures to be set. In addition, nitrogen is utilized for all pneumatic valve actuation.

A bank of four helium cylinders feeds an additional purge system for engine purging. This system is primarily intended for use in situations where nitrogen may tend to condense or cause clouding problems, such as on optical access windows in the engine chamber. The system can operate at up to 10.3 MPa (1500 psig) and supply flows of up to 0.25 kg/s (0.55 lb_m/s). Flow is controlled using a sonic orifice and measured with a differential pressure venturi.

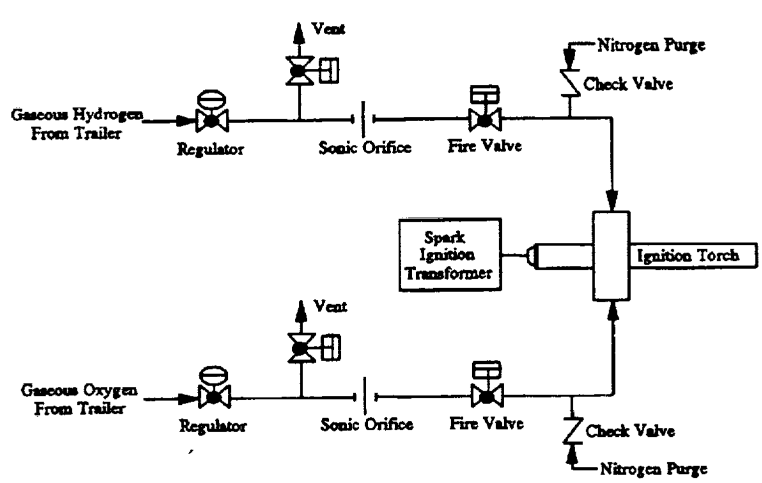

Figure 5: Schematic of the Ignition System

Cooling Systems

Gaseous hydrogen for research hardware cooling applications is supplied from a 0.95 cm o.d. (3/8 in.) branch off the main supply line. Pressure is reduced using a dome loaded pressure regulator and flow is controlled with a sonic orifice. Flow of up to 0.13 kg/s (0.275 lb_m/s) can be furnished at pressures up to 10.3 MPa (1500 psig).

Research hardware can also be cooled using water from the domestic water supply, with pressure being boosted to 1.0 MPa (150 psig) at 379 liters per minute (100 gpm) using a centrifugal pump. In addition, a high pressure cooling water supply is available from a 98 liter (26 gallon) tank which can be pressurized at up to 13.8 MPa (2000 psig). This can provide flows of 379 lpm (100 gpm) for up to 10 seconds.

ELECTRONIC SYSTEMS

Facility Controls

The control panels and monitors used in the operation of the facility are located in low consoles with data and video monitors set back behind and above the consoles. These features are shown in Figure 6 (prior to control panel installation), which also shows the access doors to the laser room (in the background of the photo on each side). The panels are composed of lighted rocker switches for operation of the remote valves and for indicating open or closed valve position, and digital panel meters to indicate important pressure and temperature values. Additional meters and the abort annunciator panel are located behind the control consoles. The monitors provide easy access to facility data and video images of the test cell and surrounding area. The computer X-windows terminal for accessing the high speed data system is also located on the main control console.

A programmable logic controller (PLC) capable of high speed control of large input and output systems is used for control of the testing in the ARPF. This controller allows the facility engineer to operate individual valves manually during pre-run and post-run operations, and then sequences all the valves automatically when the run "Start" switch is pressed. All of the timing values are entered prior to the test by the facility engineer using a numeric keypad. The PLC also stops the test when an abort signal is received, either by one of the pre-set automatic redline aborts or by a manual abort from the operator. The cause of the abort is identified by an illuminated annunciator panel. The PLC is pictured in Figure 7, which shows the rear of the control room, including the racks for amplifiers, signal conditioners, the abort system, the low speed data system, and the patchboard which connects all the signals to the various

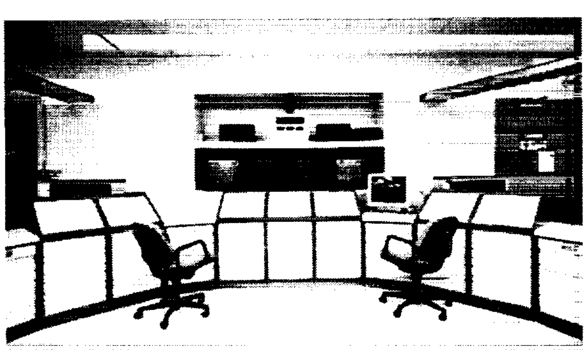

Figure 6: Front View of Control Room

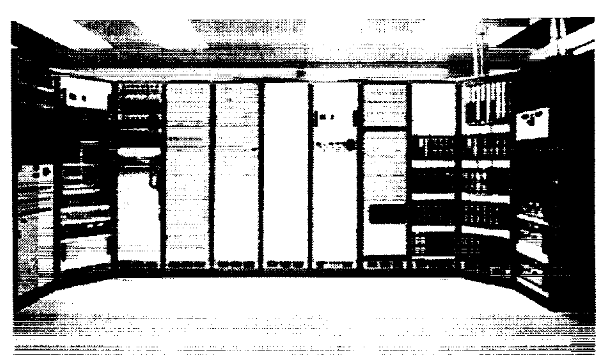

Figure 7: Rear View of Control Room

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outputs, data systems, and control devices.

The main fire valves are controlled using analog closed-looped controllers. Opening and closing rates are set using ramp generators. Valve position is typically used for the feedback signal, but chamber pressure or flow rate signals can also be used.

Instrumentation

The electronic systems in the ARPF can support a wide variety of instrumentation. A total of 69 strain gauge pressure transducer (PT) channels, 12 flow meter channels, 3 load cell channels, and 48 channels each of Type K, T, and E thermocouples (TC's) are available. Additional thermocouple types can be used if necessary. Up to 150 of the total number of channels can be sent to the high speed data system, including those which are used for facility information. The most important 64 values are amplified to increase their signal strength before being sent to the high speed data system, to prevent data loss from noise which might be introduced en route to the remotely located data system.

Data Acquisition Systems

The data acquisition systems in the ARPF provide a thorough means of monitoring facility operation and providing critical research data. The facility offers both high and low speed data acquisition systems as well as a versatile strip chart recorder and an extensive video and photographic data acquisition capability.

The transient data acquisition and reduction system, TRADAR, is used to acquire high speed research data. 150 channels of data are available, digitized by TRADAR at an aggregate rate of 600 kilosamples/sec with 16 bit resolution. The system has front end amplification and filtering, and is remotely located and supported by personnel at the NASA LeRC Research Analysis Center (RAC).

Operation of the TRADAR system is accomplished using an X-windows terminal networked to the RAC. System performance and status monitoring, raw data playback, and some real-time monitoring capability are provided by the TRADAR system through the X-terminal. Final data reduction is performed by research data programs located on the NASA LeRC scientific VAX cluster.

Low speed data acquisition is also available, using a locally housed, micro-VAX based system called ESCORT. The ESCORT system is mainly used for test cell set-up and facility data monitoring, but recording of steady state information, long duration test data, or check-out test data is possible. The ESCORT system has 128 channels, 80 of which are currently configured for use in cell 32.

The thermal strip chart recorder for the cell is used mainly for quick visual monitoring of facility parameters and engine performance during and between test runs. The recorder is capable of digitizing its 16 analog differential input signals at a rate of 200 kilosamples per second per channel, with 12 bit resolution and a 20 MHz bandwidth. This high speed capability, along with its data capture and playback feature (128 kilosamples per channel RAM), makes the recorder useful for acquisition of high frequency data.

Finally, the test cell offers extensive video and photographic data acquisition capability. Video cameras are located inside and outside of the test cell, with up to six images viewed from the control room. Two of these images, typically close-ups of the test hardware, can be recorded using a VHS tape, overlaid with time, date, and an alphanumeric label. A 400 frame per second film camera is also available for filming the test, as well as a rapid exposure 35mm camera to take snapshots during a test firing for data and presentation purposes. All of the systems described provide excellent documentation of the data from each test.

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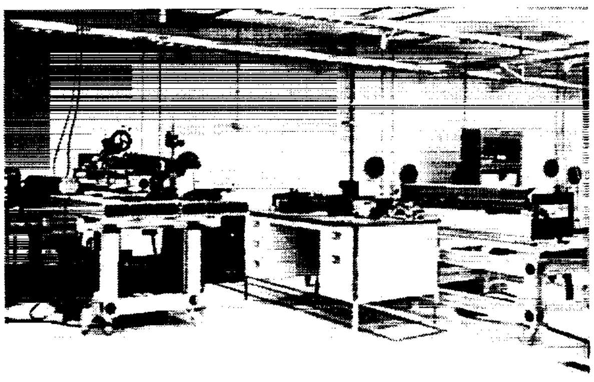

Figure 8: Partial View of Laser Room

Laser Diagnostic Systems

The ARPF laser room provides multiple laser power outlets, water cooling systems, safety interlock circuits, and the convenience of a large working space not typically found adjacent to a rocket test facility. These attributes were designed into the ARPF to make it a user-friendly, state of the art diagnostic lab capable of handling virtually any of the currently used diagnostic systems, with the flexibility to expand in the future as new techniques are developed. Part of the laser room is shown in Figure 8, which shows some of the laser equipment housed in the facility as well as an example of the optical pass-throughs which provide access to the test cell from the laser room.

Two separate power systems are available in the facility: 30 Amp, 208 volt service, and 50 Amp, 208 volt service. Multiple receptacles are located throughout the laser room so the lasers can be moved, and up to two lasers at a time can be operated on each power service. Currently, the 30 Amp service is used for Argon-ion lasers, while the 50 Amp service is used for a copper vapor laser and a neodymium YAG laser. Four cooling water stations are available, providing flow rates of up to 56.8 lpm (15 gpm) of domestic water, at pressures of 276 kPa (40 psig).

The diagnostic systems located in the facility are all assembled and operated by the researchers carrying out the test programs in the facility. Three systems can currently be used in the facility: a five Watt argon ion laser-based phase Doppler droplet analyzer, which measures both droplet size and velocity in atomization and spray fields; a ten Watt copper vapor laser flow visualization system, which uses a high speed camera synchronized with the pulsed laser to perform high quality flow visualization experiments; and a five Watt argon ion laser-based two-component laser Doppler velocimetry system for velocity measurement. The data acquisition for all the laser systems is accomplished using stand-alone PC-based systems, connected with the programmable controller to synchronize the data acquisition with the test firing.

SUMMARY

The Advanced Rocket Propulsion Facility, part of the Rocket Laboratory at the NASA Lewis Research Center, is a versatile facility for Rocket Propulsion Research up to 8.9 kN (2000 lb_f) thrust, with easy access provided for the application of laser diagnostic systems. In addition to its versatility, the Rocket Lab complex is organized to provide high data output and quick turnaround times between programs.

The main propellant systems in the facility can deliver up to 1.36 kg/s (3.0 lb_m/sec) of gaseous hydrogen, and up to 3.18 kg/s (7.0 lb_m/sec) of liquid oxygen. Chamber pressures of up to 6.9 MPa (1000 psig) are possible. Ignition is provided by a GH_2/GO_2 spark-torch igniter. Nitrogen and helium purges, water cooling, and GH_2 cooling are available to protect the facility and engine hardware during testing.

Facility operation and control is accomplished with a programmable logic controller and user-friendly control consoles, while extensive data acquisition capability is provided. This includes low and high speed digital data systems as well as a strip chart recorder and comprehensive video and photographic data acquisition capability. The large laser diagnostic room provides sufficient space for system set-up and checkout as well as easy access to the rocket engine. Electrical power and water cooling for a wide variety of laser systems is available, and equipment currently exists for flow visualization, velocimetry, and droplet size and velocity measurement.

All of these capabilities make Cell 32 of the ARPF a powerful facility for fundamental and advanced rocket propulsion research. The potential of this facility for performing research to validate new computer codes modeling rocket flow phenomena is enormous. By providing this type of information, the ARPF can greatly improve our understanding of rocket propulsion, and can play a large part in the creation of new methodologies for designing the next generation of rocket engines. The Advanced Rocket Propulsion Facility will be an important asset to NASA and the propulsion industry for many years to come.

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